U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-281 422

Source Assessment: Crushed Limestone, State of the Art

Monsanto Research Corp, Dayton, Ohio

Prepared for

Industrial Environmental Research Lab -Cincinnati, Ohio

Apr 78

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-78-004e	2.
3. RECIPIENT'S ACCESSION NO. PB281422	
4. TITLE AND SUBTITLE: SOURCE ASSESSMENT: CRUSHED LIMESTONE, State of the Art	5. REPORT DATE: April 1978 issuing date
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S): P. K. Chalekode, T. R. Blackwood, and S. R. Archer	8. PERFORMING ORGANIZATION REPORT NO. MRC-DA-747
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Monsanto Research Corporation, 1515 Nicholas Road, Dayton, Ohio 45407	10. PROGRAM ELEMENT NO. 1BB610
	11. CONTRACT/GRANT NO. 68-02-1874
12. SPONSORING AGENCY NAME AND ADDRESS: Industrial Environmental Research Laboratory - Cin., OH, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268	13. TYPE OF REPORT AND PERIOD COVERED: Task Final, 8/75-2/76
	14. SPONSORING AGENCY CODE: EPA/600/12

15. SUPPLEMENTARY NOTES
IERL-Ci project leader for this report is John F. Martin, 513/684-4417.

16. ABSTRACT

This report describes a study of atmospheric emissions from the crushed limestone industry. Crushed limestone plants emit particulates from drilling, blasting, transport on unpaved roads, crushing, screening, conveying, and stockpiling. The emission factor for total particulate from a representative plant producing 450 metric tons/hr of product is 3.5 g/metric ton. Vehicular movement on unpaved roads contributes 66% of the overall emissions and approximately 38% of the respirable particulate emissions. The hazardous constituent in the dust is free silica (1.2% by weight). Nitrogen oxides and carbon monoxide are emitted by the blasting operation, but their emission factors are small in comparison to that of particulate emissions. In order to evaluate the potential environmental effect of crushed limestone plants, source severity was defined as the ratio of the maximum time-averaged ground level concentration of an emission to the ambient air quality standard for criteria pollutants or to a modified TLV for noncriteria pollutants. The maximum source severity for particulates is 0.032; for free silica in the respirable particulate emissions, it is 0.12. Emissions from this industry in 1978 are estimated to be the same as they were in 1972.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Aggregates Air Pollution Carbon Monoxide Mines Silicone dioxide Nitrogen Oxides	Air Pollution Control Stationary Sources Source Severity Limestone Particulate Quarries silica	68A

18. DISTRIBUTION STATEMENT: Unlimited	19. SECURITY CLASS (This Report): Unclassified	21. NO. OF PAGES: 65
	20. SECURITY CLASS (This page): Unclassified	22. PRICE: A04-A01

EPA Form 2220-1 (9-73)

United States
Environmental Protection
Agency

Industrial Environmental
Research Laboratory
Cincinnati OH 45268

EPA-600/2-78-004e
April 1978

PB 281 422

Research and Development

EPA

Source Assessment: Crushed Limestone, State of the Art

Environmental Protection Technology Series

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

EPA-600/2-78-004e
April 1978

SOURCE ASSESSMENT:
CRUSHED LIMESTONE
State of the Art

by

P. K. Chalekode, T. R. Blackwood, and S. R. Archer

Monsanto Research Corporation
1515 Nicholas Road
Dayton, Ohio 45407

Contract No. 68-02-1874

Project Officer

John F. Martin
Resource Extraction and Handling Division
Industrial Environmental Research Laboratory
Cincinnati, Ohio 45268

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

DISCLAIMER

This report has been reviewed by the Industrial Environmental Research Laboratory-Cincinnati, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report contains an assessment of air emissions from the crushed limestone industry. This study was conducted to provide a better understanding of the distribution and characteristics of emissions from crushed limestone operations. Further information on this subject may be obtained from the Extraction Technology Branch, Resource Extraction and Handling Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

PREFACE

The Industrial Environmental Research Laboratory (IERL) of the U.S. Environmental Protection Agency (EPA) has the responsibility for insuring that pollution control technology is available for stationary sources to meet the requirements of the Clean Air Act, the Federal Water Pollution Control Act, and solid waste legislation. If control technology is unavailable, inadequate, uneconomical, or socially unacceptable, then financial support is provided for the development of the needed control techniques for industrial and extractive process industries. Approaches considered include process modifications, feedstock modifications, add-on control devices, and complete process substitution. The scale of the control technology programs ranges from bench- to full-scale demonstration plants.

IERL has the responsibility for developing control technology for a large number of operations (more than 500) in the chemical and related industries. As in any technical program, the first step is to identify the unsolved problems. Each of the industries is to be examined in detail to determine if there is sufficient potential environmental risk to justify the development of control technology by IERL.

Monsanto Research Corporation (MRC) has contracted with EPA to investigate the environmental impact of various industries that represent sources of pollutants in accordance with EPA's responsibility, as outlined above. Dr. Robert C. Binning serves as MRC Program Manager in this overall program, entitled "Source Assessment," which includes the investigation of sources in each of four categories: combustion, organic materials, inorganic materials, and open sources. Dr. Dale A. Denny of the Industrial Processes Division at Research Triangle Park serves as EPA Project Officer for this series. Reports prepared in this program are of two types: Source Assessment Documents and State-of-the-Art Reports.

Source Assessment Documents contain data on pollutants from specific industries. Such data are gathered from the literature, government agencies, and cooperating companies. Sampling and analysis are also performed by the contractor when the available information does not adequately characterize the source pollutants. These documents contain all of the information necessary for IERL to decide whether a need exists to develop additional control technology for specific industries.

State-of-the-Art Reports include data on pollutants from specific industries which are also gathered from the literature, government agencies and cooperating companies. However, no extensive sampling is conducted by the contractor for such industries. Sources in this category are considered by EPA to be of insufficient priority to warrant complete assessment for control technology decisionmaking. Therefore, results from such studies are published as State-of-the-Art Reports for potential utility by the government, industry, and others having specific needs and interests.

This State-of-the-Art Report contains data on air emissions from the crushed limestone industry. This project was initiated by the Chemical Processes Branch of the Industrial Processes Division at Research Triangle Park; Mr. D. K. Oestreich served as EPA Project Leader. The project was transferred to and completed by the Resource Extraction and Handling Division, IERL-Cincinnati, under Mr. John F. Martin.

ABSTRACT

This report describes a study of air pollutants emitted by the crushed limestone industry. The potential environmental effect of the source was evaluated using source severity (defined as the ratio of the maximum ground level concentration of an emission to a hazard factor).

In 1972, there were 1,374 crushed limestone processing plants operating 2,904 quarries in the United States. The representative crushed limestone plant produces 450 metric tons/hr and emits particulates from several operations, including drilling, blasting, transport on unpaved roads, crushing, screening, conveying, and stockpiling. The emission factor for total particulates emitted from the representative plant is 3.5 g/metric ton, and vehicular movement on unpaved roads contributes 66% of the overall emissions. Approximately 38% of the respirable particulate emissions originate from vehicular movement on unpaved roads, and the respirable particulate emission factor is 0.6 g/metric ton. The hazardous constituent in the dust is free silica (1.2% by weight), prolonged exposure to which may result in the development of a pulmonary fibrosis known as silicosis. Nitrogen oxides and carbon monoxide are emitted by the blasting operation, but the emission factors (and source severities) for these emissions are small in comparison to those of particulate emissions.

The maximum source severity for particulates is calculated as 0.032. The affected population is defined as the population living beyond the plant boundary where the severity is 0.1 or greater. The population affected by a severity of 0.1 due to total particulate emissions is thus zero. Similarly, the source severity due to free silica in the respirable particulate emissions is 0.12, and the population affected by a severity of 0.1 is 11 persons. The emissions from the crushed limestone industry (as well as the output of the industry) are estimated to be the same in 1978 as they were in 1972.

This report was submitted in partial fulfillment of Contract 68-02-1874 by Monsanto Research Corporation under the sponsorship of the U.S. Environmental Protection Agency. The study covers the period August 1975 to February 1976.

CONTENTS

Foreword iii
Preface iv
Abstract vi
Figures viii
Tables viii
Abbreviations and Symbols ix
Conversion Factors and Metric Prefixes xi

1. Introduction 1
2. Summary 2
3. Source Description 5
   Process description 5
   Factors affecting emissions 7
   Geographical distribution 8
4. Emissions 10
   Selected pollutants 10
   Characteristics 10
   Definition of representative source 11
   Source severity 13
5. Control Technology 16
   State of the art 16
   Future considerations 16
6. Growth and Nature of the Industry 20
   Present technology 20
   Emerging technology 20
   Production trends 20

References 22
Appendices

A. Literature survey 25
B. Sampling details and results 31
C. Source severity and affected population 46

Glossary 49

FIGURES

Number		Page
1	Simplified flowsheet for lime and limestone products.	6

TABLES

1	Mass Emissions from Various Operations in the Crushed Limestone Industry	4
2	Crushed Limestone Sold or Used by Producers in the United States in 1972, by State and Respective Population Density	9
3	State and Nationwide Particulate Emission Burdens from Crushed Limestone	12
4	Pollutant Severity Equations	15
5	Source Severity and Affected Population for Emissions from the Crushed Limestone Industry	15

ABBREVIATIONS AND SYMBOLS

A	-- cross-sectional area of the falling granules, cm^2
a. . .d, f	-- variable exponents and coefficients used in numerous methematical manipulations
B	-- width of conveyor belt, cm
CHI	-- measured concentration less background, $\mu g/m^3$
D	-- representative distance from the major source, m
D_T	-- total dose, $g\text{-}s/m^3$
e	-- natural logarithm base, 2.72
E	-- emission factor, g/metric ton
E_D	-- function of five variables that influence dust emissions from drilling operations
F	-- hazard factor, g/m^3
G	-- gravitational acceleration, 980 cm/s^2
H	-- height of material fall, cm
m_1, m_2	-- slopes used in calculating distances to samplers
M	-- belt load, g/cm^2
P	-- production rate of crushed limestone, metric tons/hr
Q	-- emission rate, kg/hr or g/s (Equations 1 and 2)
Q_D	-- line source emissions per length of line, g/m
Q_T	-- total release, g
R	-- specific formation of airborne respirable dust, g
S	-- maximum source severity, dimensionless
S_0. . .S_4	-- high-volume sampler locations
TLV	-- threshold limit value, g/m^3
u	-- 4.5 m/s (approximate U.S. average wind speed)
U_B	-- linear speed of the conveyor belt, cm/s
x	-- downwind distance
x_i, y_i	-- Cartesian coordinates used to relate position of the ith sampler to the source

ABBREVIATIONS AND SYMBOLS

X, X_i	-- downwind distance from source along the dispersion centerline
x_c	-- crosswind distance from the line source, m
Y, Y_i	-- lateral distance from dispersion centerline to sampler, m
Z	-- vertical distance from the X-Y plane of the source to the sampler plane
α	-- angle defined for use in calculating sampler position, rad
θ	-- wind azimuth angle with respect to the y axis, rad
π	-- a constant, 3.14
$\overline{\rho}_C$	-- material density of coal, g/cm^3
σ	-- overall standard deviation, m
σ_y	-- horizontal standard deviation of plume dispersion, m
σ_z	-- vertical standard deviation of plume dispersion, m
σ_{zI}	-- instantaneous vertical dispersion parameter, m
χ	-- ground level concentration, g/m^3
χ_i	-- ground concentration at coordinate location (X_i, Y_i, 0), g/m^3
χ_{max}	-- maximum ground level concentration, g/m^3
$\overline{\chi}_{max}$	-- maximum time-averaged ground level concentration, g/m^3
ψ	-- dose, $g\text{-}s/m^3$

CONVERSION FACTORS AND METRIC PREFIXES[a]

CONVERSION FACTORS

To convert from	To	Multiply by
Centimeter	Foot	3.281×10^{-2}
Centimeter^2 (cm^2)	Inch^2	1.550×10^{-1}
Centimeter^3 (cm^3)	Inch^3	6.102×10^{-2}
Kilogram (kg)	Pound-mass (avoirdupois)	2.204
Kilogram (kg)	Ton (short, 2,000 lb-mass)	1.102×10^{-3}
Kilometer^2 (km^2)	Mile^2	3.860×10^{-1}
Meter (m)	Foot	3.281
Meter^2 (m^2)	Foot^2	1.076×10^{1}
Meter^3 (m^3)	Foot^3	3.531×10^{1}
Meter^3 (m^3)	Gallon (U.S. liquid)	2.642×10^{2}
Metric ton	Pound-mass	2.205×10^{3}
Radian (rad)	Degree (°)	5.730×10^{1}

METRIC PREFIXES

Prefix	Symbol	Multiplication factor	Example
Kilo	k	10^{3}	1 kg = 1×10^{3} grams
Centi	c	10^{-2}	1 cm = 1×10^{-2} meter
Milli	m	10^{-3}	1 mm = 1×10^{-3} meter
Micro	μ	10^{-6}	1 m = 1×10^{-6} meter

[a]Metric Practice Guide. ASTM Designation E 380-74, American Society for Testing and Materials, Philadelphia, Pennsylvania, November 1974. 34 pp.

SECTION 1

INTRODUCTION

The conversion of naturally occuring limestone to a crushed form involves mining from open quarries and processing at finishing plants. The mining and processing operations create air pollution problems.

An investigation of crushed limestone operations was conducted to provide a better understanding of the distribution and characteristics of emissions from these activities than had been previously available in the literature. Data collection emphasized the accumulation of sufficient information to ascertain the need for developing control technology in this industry.

This document contains information on the following items:

- A method to estimate the emissions due to crushed limestone processing
- Composition of emissions
- Hazard potential of emissions
- Geographical distribution and source severity
- Trends in the crushed limestone industry and their effects on emissions
- Type of control technology used and proposed

SECTION 2

SUMMARY

The crushed limestone industry converts naturally occurring limestone deposits to a form that is used predominantly (67% of the output) by the construction industry. The 1,374 processing plants, which operate 2,904 quarries in the United States, produced 6.1×10^8 metric tons[a] of crushed limestone in 1972. This represented 37% of the output of the aggregate industry (crushed limestone, granite, stone, sand and gravel, and sandstone, quartz and quartzite). Contingency forecasts of crushed limestone demands in the year 2000 have been reported to be 1.2×10^9 metric tons to 2.0×10^9 metric tons.

Atmospheric emissions of particulates occur from several unit operations: drilling, blasting, transport on unpaved roads, crushing, screening, conveying, and stockpiling. The estimated emission factor available in the published literature, 5.65 grams of suspended particulate per kilogram of processed material, was checked by onsite sampling. The emission factor for total particulates from crushed limestone processing is 3.5 g/metric ton, and the emission factor for respirable particulates is 0.6 g/metric ton. Total particulate emissions from vehicular movement on unpaved roads (between quarry and plant) contribute about 66% of the overall emissions. Similarly, about 35% of the respirable particulate emissions are from vehicular movement on unpaved roads. The hazardous constituent in the dust is free silica (1.2% average), prolonged exposure to which may result in the development of silicosis.

The total national emissions from the crushed limestone industry account for less than 0.013% of national emissions and less than 0.07% of any state emissions.

A representative crushed limestone plant produces 450 metric tons/hr and emits dust at the rate of 0.27 kg/hr respirable particulates (less than 7 μm) and 1.6 kg/hr total particulates (less than 100 μm).

To assess the source severity, the ratio of the maximum time-averaged ground level concentration at the representative plant

---

[a] 1 metric ton equals 10^6 grams; conversion factors and metric system prefixes are presented in the prefatory material.

boundary to the pollutant hazard factor is used. The hazard factor is defined as the EPA primary air quality standard. When EPA criteria do not exist, an adjusted threshold limit value (TLV®) is used which corrects for exposure time and for the exposure of the general population. The maximum source severity due to free silica emissions (respirable fraction) from a representative plant is 0.14.

Nitrogen oxides and carbon monoxide are emitted by the blasting operation with respective emission factors of 2.85 g/metric ton and 1.68 g/metric ton of material blasted. The maximum source severities due to nitrogen oxides and carbon monoxide are 0.089 and 1.7×10^4, respectively.

Table 1 summarizes the severity and contributions of total particulates and free silica emissions from the various unit operations.

This industry is concentrated near limestone deposits, adjacent to large, rapidly expanding urban areas, and in areas where largescale public and private works are under construction. The distribution of plants with respect to the size of localities shows that free silica emissions from a representative crushed limestone plant affect a population of 11 persons down to a severity of 0.1. The affected population is based on respirable particulate emissions.

The output of the industry and its emissions are estimated to be the same in 1978 as they were in 1972.

TABLE 1. MASS EMISSIONS FROM VARIOUS OPERATIONS IN THE CRUSHED LIMESTONE INDUSTRY

Unit operation	Total particulates					Free silica	
	Emission factors, g/metric ton	U.S. total, kg/yr	Percent of total	Severity for representative plant	Percent respirable	U.S. total, kg/yr	Severity for representative plant
Drilling	0.11	67,000	3	-[a]	10	80	-[a]
Blasting	0.075	46,000	2	-[a]	17	100	-[a]
Loading at the quarry	0.0015	9,000	-[a]	-[a]	0	0	0
Vehicular traffic[b]	2.3	1,403,000	66	0.021	10	1,680	0.05
Primary crushing	0.56	341,000	16	0.005	30	1,240	0.04
Primary screening	0.0016	9,800	-[a]	-[a]	30	-[a]	-[a]
Secondary crushing	0.14	85,000	4	0.001	53	560	0.02
Screening screening	0.0009	5,500	-[a]	-[a]	53	-[a]	-[a]
Conveying	0.32	195,000	9	0.003	30	700	0.03
Stockpiles	-[a]	-[a]	-[a]	-[a]	-[a]	-[a]	-[a]
Unloading at stockpiles	-[a]	-[a]	-[a]	-[a]	-[a]	-[a]	-[a]
TOTAL[c]	3.5	2,135,000	100	0.032	17	4,360	0.14

[a] Negligible.

[b] On unpaved road between quarry and plant.

[c] Total may not add to figure shown due to rounding.

SECTION 3

SOURCE DESCRIPTION

PROCESS DESCRIPTION

Emission Sources

The conversion of naturally occuring limestone deposits into a crushed form involves a series of physical operations similar to those used in the crushed granite and crushed stone industries as shown schematically in Figure 1. The deposits are first loosened by drilling and blasting, then loaded and transported to the processing plant by trucks or belt conveyors. Processing includes such operations as crushing, pulverizing, screening, conveying and stockpiling. After processing, the crushed material can be used for construction purposes, or it can be processed further for the manufacture of quicklime and of hydrated lime.

Fine particulate (less than 7 μm) emission sources in the crushed limestone industry can be divided into two categories: 1) sources associated with actual processing, such as crushing, screening, and transfer operations; and 2) fugitive dust sources, such as vehicle traffic on unpaved roads, transport operations, and stockpiles. Quarrying operations such as drilling, blasting, and loading are also fugitive dust sources.

This study is confined to an evaluation of emissions from crushed limestone processing and does not include those from quicklime or hydrated lime operations (Figure 1).

Source Composition

Limestone is a sedimentary rock composed primarily of calcium carbonate ($CaCO_3$) and secondarily of magnesium carbonate ($MgCO_3$), including varying percentages of impurities. Limestone is generally classified into the following types:

- High-calcium--The carbonate content is composed essentially of calcium carbonate with a magnesium carbonate content of no more than 5% (usually less).

- Magnesian--This rock, which contains both carbonates, possesses a magnesium carbonate content of 5% to 20%.

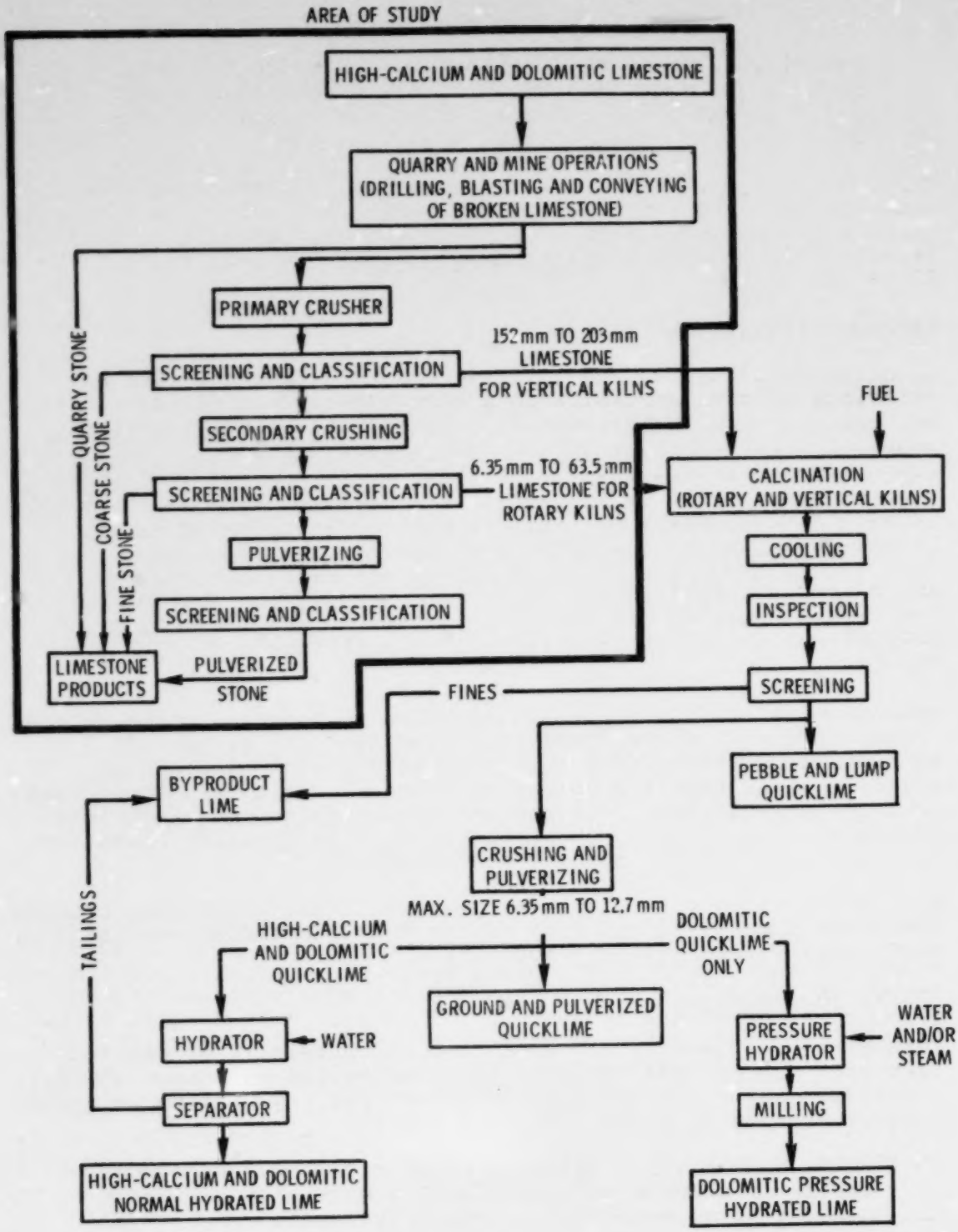

Figure 1. Simplified flowsheet for lime and limestone products.

- Dolomitic--This rock contains over 20% $MgCO_3$; however, the maximum $MgCO_3$ content will not exceed 45.6%, the exact amount contained in a true, pure, equimolecular dolomite, with the balance $CaCO_3$.

Chemical analyses of different types of U.S. limestones show that the lime (CaO) content ranges from about 29% to 55%, the magnesia (MgO) content ranges from 0% to 21%, the alumina (Al_2O_3) content is less than 6%, and the iron oxide (Fe_2O_3) content is less than 2% (1).

FACTORS AFFECTING EMISSIONS

Calculation of the source severity and the state and national emissions burdens necessitates a knowledge of the emission rate for every source in the country. Conducting emission measurements on a sourcebysource basis was impractical due to the large number of individual sources and the diversity of source types. A method was therefore developed to derive an emission factor as grams of particulates emitted per metric ton of crushed limestone processed.

The emission rate for each of the source types is estimated as the product of the emission factor and the crushed limestone production rate. This relationship can be stated as shown in Equation 1.

$$Q = E(P) \qquad (1)$$

where Q = emission rate of particulates, g/hr

E = emission factor for particulates, g/metric ton of crushed limestone processed

P = production rate of crushed limestone, metric tons/hr

The overall emissions from crushed limestone operations are due to drilling, blasting, loading, vehicular movement on unpaved roads (between quarry and plant), crushing, conveying, screening, and stockpiling. Emissions from all of these unit operations (except blasting) are influenced by particle size distribution, rate of handling, moisture content of the handled material, and type of equipment used.

A detailed literature survey was conducted to obtain published data on the extent to which various factors influence the overall emissions, and on the relative contributions of the unit operations to overall emissions. Although estimates of emission

---

(1) Kirk-Othmer Encyclopedia of Chemical Technology, Second Edition, Vol. 12. John Wiley & Sons, Inc., New York, New York, 1969. pp. 414-423.

factors for some unit operations are available in the published literature, no studies were conducted or reported to validate the estimated emission factors (Appendix A).

A sampling of emissions from two crushed limestone plants was conducted (see Appendix B for details and results of sampling). The results show that vehicular traffic on unpaved roads between the quarry and plant contribute 66% of the total particulate emissions, and that primary crushing operations contribute 16% of the overall emissions. Similarly, 38% of the respirable particulate emissions are from vehicular traffic on unpaved roads, and 28% of the respirable particulate emissions are from primary crushing operations.

The factors believed to influence emissions from vehicular movement on unpaved roads are vehicle speed, vehicle weight and crosssectional area, number of wheels, tire width, particle size distribution, and moisture content of unpaved road surface material. Though considerable information is available on the magnitude of unpaved road emissions, little has been done to correlate the emissions with soil or vehicle characteristics.

GEOGRAPHICAL DISTRIBUTION

In 1972 there were 1,374 crushed limestone processing plants (2) operating 2,904 quarries (personal communication with W. Pajalich, Bureau of Mines, Washington, D.C., 15 October 1975) with a total total output of 6.1×10^8 metric tons. Pennsylvania ranked first with 5.1×10^7 metric tons, followed by Illinois, Florida, Ohio Texas, Missouri, Michigan, Tennessee, New York and Kentucky. Together, these 10 states accounted for 66% of the total crushed limestone production in the United States (3).

Table 2 gives the crushed limestone output by state in the United States and the respective population densities.

Geographically, the crushed limestone industry is concentrated near limestone deposits, adjacent to large, rapidly expanding urban areas, and in areas where large-scale public and private works are under construction.

---

(2) 1972 Census of Mineral Industries, Subject Series: General Summary. MIC 72(1)-1, U.S. Department of Commerce, Washington, D.C., 1975. 174 pp.

(3) Mineral Industry Surveys. U.S. Department of the Interior, Washington, D.C., 1972. 12 pp.

TABLE 2. CRUSHED LIMESTONE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1972, BY STATE AND RESPECTIVE POPULATION DENSITY

State	Population density, persons/km^2	Production in 1972, 10^3 metric tons
Alabama	27	14,800
Arizona	7	2,200
Arkansas	15	4,700
California	50	16,400
Colorado	9	3,000
Connecticut	240	200
Florida	49	48,200
Georgia	31	5,600
Hawaii	49	1,100
Idaho	4	
Illinois	78	51,100
Indiana	57	24,500
Iowa	20	24,900
Kansas	11	12,700
Kentucky	32	31,100
Maine	12	
Maryland	177	13,100
Massachusetts	274	800
Michigan	60	35,200
Minnesota	18	4,400
Mississippi	13	400
Missouri	27	37,800
Montana	2	1,300
Nebraska	8	3,900
Nevada	2	2,000
New Jersey	366	
New Mexico	3	1,300
New York	145	31,200
North Carolina	39	
North Dakota	2	
Ohio	102	43,100
Oklahoma	15	16,400
Oregon	9	
Pennsylvania	103	51,300
Rhode Island	312	
South Carolina	34	
South Dakota	2	1,500
Tennessee	38	32,400
Texas	17	38,600
Utah	5	2,100
Vermont	19	1,100
Virginia	46	17,300
Washington	29	9,700
Wisconsin	31	14,300
Wyoming	1	1,400
Undistributed		7,500
TOTAL		610,000[a]

Note.—Blanks denote information withheld owing to confidential nature of data; included with "undistributed."

[a]Data do not add to total shown due to independent rounding.

SECTION 4

EMISSIONS

SELECTED POLLUTANTS

Emissions from crushed limestone operations are classed as nuisance particulates. They are considered to be toxic only when they contain a toxic component such as free silica (4, 5).

The prolonged inhalation of dusts containing free silica may result in the development of a disabling pulmonary fibrosis known as silicosis. The action of silica on the lungs results in the production of a diffuse, nodular, progressive fibrosis that may continue to increase for several years after exposure is terminated. The first and most common symptoms of uncomplicated silicosis are shortness of breath on exertion and a dry cough. When the disease advances, the shortness of breath becomes worse and the cough more troublesome. Further progress of the disease results in marked fatigue, loss of appetite, pleuritic pain, and total incapacity to work. Extreme cases may eventually result in death from destruction of the lung tissues (4).

The American Conference of Governmental Industrial Hygienists has suggested a TLV (in milligrams per cubic meter) of 10/(percent quartz + 2) for respirable dusts containing quartz or free silica. Dusts with less than 1% silica are termed "inert," and their suggested TLV is 10 mg/m^3 (5).

CHARACTERISTICS

Mass Emissions

The mean emission factor for respirable particulates is 0.6 g/metric ton of limestone processed through the primary crusher. The mean emission factor for total particulates is 3.5 g/metric ton. Total particulate emissions due to vehicular

(4) Sax, N. I. Dangerous Properties of Industrial Materials, Third Edition. Reinhold Book Corporation, New York, New York, 1968. pp. 1088-1089.

(5) TLVs® Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1976. American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1976. p. 32.

movement on unpaved roads between the quarry and plant contribute 66% of the overall emissions. Similarly, 38% of the respirable particulate emissions are from vehicular movement on unpaved roads. The foregoing results are based on a sampling of two crushed limestone plants (see Appendix B). The total particulate emission factor generated in this study is less than the estimated emission factor reported in literature published prior to this study. The emission factors for nitrogen oxides and carbon monoxide, respectively, are 2.85 g/metric ton and 1.68 g/metric ton (6).

The aforementioned emission factor for total particulates was used to estimate the statewide emissions from crushed limestone processing, as shown in Table 3. The state emission burden is calculated as the percent contribution of total particulate emission rates from crushed limestone processing in a state to the overall total particulate emission rates in that state. Table 3 displays the state and nationwide burdens. The emissions of total particulates due to crushed limestone processing contribute 0.07% or less to the overall particulate emissions in each of the states in the United States.

Composition of Emissions

An analysis of the emissions from crushed limestone operations (Appendix B) shows that free silica, constituting 1% to 2% by weight, is the only known hazardous component. Remaining constituents are considered inert.

DEFINITION OF REPRESENTATIVE SOURCE

The size of crushed limestone plants ranges from about 136 metric tons/hr to 1,090 metric tons/hr with the average of 450 metric tons/hr being the size of the representative plant (personal communication with F. Renninger, National Crushed Stone Association, Washington, D.C., 7 November 1975).

The mean emission factor was determined by sampling two crushed limestone plants whose production rates were similar to that of the representative plant (Appendix B). Thus, the representative source emits dust at a rate of 0.27 kg/hr respirable particulates (less than 7 μm) and 1.6 kg/hr total particulates.

The representative population density, taken as the average population density of the states weighted on the basis of their crushed limestone production, is 58 persons/km^2. The representative distance from the plant is defined using the major contributing source within the plant as the reference point. The

---

(6) Blackwood, T. R., P. K. Chalekode, and R. A. Wachter. Source Assessment: Crushed Stone. Contract 68-02-1874, U.S. Environmental Protection Agency, Cincinnati, Ohio, July 1977. 91 pp.

TABLE 3. STATE AND NATIONWIDE PARTICULATE EMISSION BURDENS FROM CRUSHED LIMESTONE

State	Total particulate emissions from crushed limestone processing (1972), metric tons/yr	Overall particulate emissions (7) 10^3 metric tons/yr	Contribution of crushed limestone emissions to overall state emissions, %
Alabama	52	1,179	
Arizona	8	73	0.01
Arkansas	16	138	0.01
California	57	1,006	0.01
Colorado	11	201	
Connecticut	1	40	
Florida	169	226	0.07
Georgia	20	405	
Hawaii	4	62	0.01
Illinois	179	1,143	0.02
Indiana	86	748	0.01
Iowa	87	216	0.04
Kansas	44	348	0.01
Kentucky	109	546	0.02
Maryland	46	495	0.01
Massachusetts	3	96	
Michigan	123	706	
Minnesota	15	266	0.01
Mississippi	1	168	
Missouri	132	202	0.06
Montana	6	273	
Nebraska	14	95	
Nevada	7	94	0.01
New Mexico	5	103	
New York	109	160	0.07
Ohio	151	1,766	0.01
Oklahoma	57	94	0.06
Pennsylvania	180	1,811	0.01
South Dakota	5	52	0.01
Tennessee	113	410	0.03
Texas	135	549	0.02
Utah	7	72	0.01
Vermont	4	15	0.03
Virginia	61	477	0.01
Washington	4	162	
West Virginia	34	214	0.02
Wisconsin	50	412	0.01
Wyoming	5	75	0.01
Other states[a]	26	1,662	
TOTAL	2,135	16,762[b]	0.013[c]

Note.—Blanks indicate negligible contribution.

[a]Includes Idaho, Maine, New Jersey, North Carolina, North Dakota, Oregon, *Rhode Island, and South Carolina.*

[b]Includes overall particulate emissions from Alaska, Delaware, District of Columbia, and Louisiana, which do not have crushed limestone plants.

[c]Since respirable particulate is 14.2% of total particulate emissions, national emission burden due to respirable particulate emissions from crushed limestone emissions is 0.002%.

---

(7) 1972 National Emissions Report. EPA-450/2-74-012, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 1974. 422 pp.

distance of the plant boundaries from this reference point is taken as the radius of a circle whose area is equal to the area of the representative plant. The area of a representative crushed limestone plant was assumed to be similar to that of a representative crushed stone plant (0.53 km^2), and the resulting representative distance to the plant boundary is 410 m (6).

The output of the representative plant and its emissions should follow industry trends; they are estimated to be the same in 1978 as they were in 1972.

SOURCE SEVERITY

The source severity, used to indicate the hazard potential of the representative emission source, is determined using the ratio of the maximum ground level concentration ($\overline{\chi}$) to a hazard factor (F). A mathematical model describing the dispersion of pollutants in the atmosphere is employed to calculate the source severity, S (which equals $\overline{\chi}/F$). For open sources, the model employs the concentration of a pollutant occurring at a ground level point source on the plant boundary. This is the maximum concentration that can occur at one point in time and, thus, is considered a worst-case condition. The hazard factor is derived from ambient air quality criteria or reduced threshold limit values.

Ground Level Concentration

The minimum distance from the major contributing emission source to the representative crushed limestone plant boundary is 410 m, as shown in Section 4. This is the minimum distance at which public exposure to the pollutant could occur.

The following formula in conjunction with class C meteorological conditions (approximate U.S. average) was used to calculate χ_{max} (the maximum ground level, instantaneous concentration) (8):

$$\chi_{max} = \frac{Q}{\pi \sigma_y \sigma_z u} \qquad (2)$$

where Q = mass emission rate, g/s
π = 3.14
σ_y = 0.209 ($x^{0.903}$)
σ_z = 0.113 ($x^{0.911}$)
u = 4.5 m/s (approximate U.S. average wind speed)

The instantaneous ground level concentration for total particulates at 410 m is 24 $\mu g/m^3$. This must be corrected to the time-

(8) Turner, D. B. Workbook of Atmospheric Dispersion Estimates. Public Health Service Publication No. 999-AP-26, U.S. Department of Health, Education, and Welfare, Cincinnati, Ohio, May 1970. 84 pp.

averaged maximum, $\bar{\chi}_{max}$, for 24 hr as described by Nonhebel (9) so that the mean concentration becomes 8.4 $\mu g/m^3$. Therefore, the maximum ground level concentration at the boundary of the representative plant during a 24-hr period is 8.4 $\mu g/m^3$ above background levels (worst case).

Hazard Factor

Since no ambient air quality criterion exists for free silica, the hazard factor, F, is defined as follows:

$$F = \frac{8}{24}\left(\frac{1}{100}\right)TLV \qquad (3)$$

The derivation of F utilizes the TLV corrected from 8-hr to 24-hr exposure with a safety factor of 100 applied to this calculation. The free silica hazard factor for the purposes of this report is calculated as 10.4 $\mu g/m^3$, comparable to that for respirable emissions since the TLV is for respirable emissions. For total particulates, F shall be defined as the 24-hr ambient air quality standard of 260 $\mu g/m^3$.

Source Severity

For the representative crushed limestone plant, the maximum severity is determined from the ratio of the maximum time-averaged ground level concentration of the emission species to the hazard factor for the species ($\bar{\chi}_{max}/F$). The maximum time-averaged ground level concentration is related to the mass emission rate, Q (in grams per second) of a pollutant and, for open sources, to the representative distance, D, from the source to the plant boundary.

Using the approach described above, the equations in Table 4 were used to determine the severity of criteria and noncriteria pollutants from the crushed limestone industry (10). The equations simplify the calculation of both severity and, ultimately, affected population.

Source severities due to and the population affected by emissions of criteria and noncriteria pollutants from the crushed limestone industry are shown in Table 5. Severity can also be obtained by calculating the ratio $\bar{\chi}_{max}/F$. Thus for particulate ($\bar{\chi}_{max}$ equals 8.4 $\mu g/m^3$ and F equals 260 $\mu g/m^3$), the severity is 0.32. Sample calculations for source severity and affected population are provided in Appendix C.

(9) Nonhebel, G. Recommendations on Heights for New Industrial Chimneys. Journal of the Institute of Fuel, 33:479, 1960.

(10) Blackwood, T. R., and R. A. Wachter. Source Assessment: Coal Storage Piles. Contract 68-02-1874, U.S. Environmental Protection Agency, Cincinnati, Ohio, July 1977. 96 pp.

TABLE 4. POLLUTANT SEVERITY EQUATIONS

Pollutant	Severity equation	
Particulate	$S = \frac{4{,}020\ Q}{D^{1.81}}$	(4)
Nitrogen oxides	$S = \frac{22{,}200\ Q}{D^{1.90}}$	(5)
Carbon monoxide	$S = \frac{44.8\ Q}{D^{1.81}}$	(6)
Noncriteria pollutant	$S = \frac{316\ Q}{TLV \cdot D^{1.81}}$	(7)

TABLE 5. SOURCE SEVERITY AND AFFECTED POPULATION FOR EMISSIONS FROM THE CRUSHED LIMESTONE INDUSTRY

Type of pollutant	Source severity	Affected population[a]
Total particulates	0.032	0
Free silica	0.14	11
Nitrogen oxides	0.089	0
Carbon monoxide	0.00017	0

[a]Population affected down to a severity of 0.1.

Since the maximum source severity for total particulates is less than 0.1 at the plant boundary (Appendix C), the affected population is zero. Similarly, the maximum source severity for free silica in the respirable particulates is 0.14 and, for a representative population density of 58 persons/km^2, the population affected by a severity of 0.1 is 11 people residing within 0.49 0.49 km from the plant boundary. The maximum source severities for nitrogen oxides (NO_x) and carbon monoxide (CO) from blasting are 0.089 and 0.00017, respectively, with zero affected population.

SECTION 5

CONTROL TECHNOLOGY

STATE OF THE ART

Many plants control emissions from unpaved roads by frequently spraying the roads with water or oil. Some plants use a wet suppression system and/or baghouse to suppress dust emissions from crushing, screening, and conveying operations.

Dust generated from various operations is dependent upon the dryness of the handled material; hence, any method used to add moisture is helpful in controlling dust levels. Natural phenomena such as rain or snow and in-process washing or spraying operations are good examples of methods for controlling dust.

FUTURE CONSIDERATIONS

The fugitive and point sources of dust limestone processing are drilling, blasting, loading, unpaved road transport, crushing, screening, conveying, and stockpiling.

Dust emissions from dry percussion drilling operations can be controlled by adding water or water mixed with a surfactant to the air used for flushing drill cuttings from the hole. Dilution ratios range from 800 to 3,000 parts of water to 1 part surfactant. An 89-mm-diameter hole requires 0.026 m^3/hr of solution. This permits the drill cutting to be blown from the hole as damp, dust-free pellets (11).

In conventional coal mining, water-filled plastic bags with or without solid stemming material (clay) are used for stemming dust emissions from blast holes. This method reduces dust concentrations by 20% to 80% and explosive consumption by about 10% (12). Instead of liquids, "thixotropic" cellulose or bentonite pastes can be used. Such pastes are gelatinous in repose but liquefy when disturbed. A similar control method may be applicable for reducing particulate emissions from blasting in limestone mining.

---

(11) Jones, H. R. Fine Dust and Particulates Removal. Noyes Data Corporation, Park Ridge, New Jersey, 1972. 307 pp.

(12) Grossmueck, G. Dust Control in Open Pit Mining and Quarrying. Air Engineering, 10(25):21, 1968.

Release of carbon monoxide, nitrogen oxides, and other gases such as aldehydes and hydrogen can be curtailed by having a dry blast hole and by properly carrying out the detonation to prevent incomplete combustion.

Loading of the blasted limestone into trucks by front-end loaders results in dust emissions. Wetting of the broken stone with water or water mixed with a surfactant will alleviate the dust emissions. Emissions due to wind erosion during transport can be reduced by covering the load with a tarpaulin or wetting its surface with water or water mixed with chemicals.

Water application is also an effective method for controlling emissions from unpaved roads; however, approximately 5% to 8% moisture (by weight) must be applied to suppress the dust emissions (13). Additives such as calcium chloride can be used to reduce the surface tension of water so that the dust can be wetted with less water. Calcium chloride can be applied at a cost of approximately $\$0.15/m^2$ treated per year (14). The major problems involved in its use are the corrosion of vehicle bodies and leaching by rainwater or melting snow.

Another effective method of dust control is to mix stabilizing chemicals into the road surface to a depth of approximately 20 mm to 50 mm (15). One cement company uses a special emulsion agent[a] and a treatment which involves spraying a solution of 4 parts of water and 1 part of the emulsion agent at the rate of $0.009\ m^3/m^2$ of the road surface. Certain pretreatment measures such as working the road surface into a stiff mud are necessary to prevent the binder in this emulsion agent from sticking to the vehicles. Periodic maintenance using a 1:7 emulsion agent/water solution spray keeps the emulsion agent binder active. This dust control program was found to give 3 yr of service at a total cost of $\$0.12/m^2$.

---

[a]Coheren, supplied by Golden Bears Division, Wetco Chemicals Company.

---

(13) Dust Suppression. Rock Products, 75:137, May 1972.

(14) Vandegrift, A.E., L. J. Shannon, P. G. Gorman, E. W. Lawless, E. E. Sallee, and M. Reichel. Particulate Pollutant Systems Study, Volume III: Handbook of Emission Properties. Contract EPA-22-69-104, U.S. Environmental Protection Agency, Durham, North Carolina, May 1971. 607 pp.

(15) Significant Operating Benefits Reported from Cement Quarry Dust Control Programs. Pit and Quarry, 63(7):116, 1971.

In some counties in Iowa, mixing cutback asphalt into the road surface to a depth of 50 mm to 80 mm has been investigated (16). This type of surface treatment reduces dust emissions, but it requires periodic maintenance such as patching of the potholes.

Treating the road surface with oil once a month is another efficient method of controlling unpaved road dust emissions. The cost for such applications is estimated to be $\$0.10/m^2$ treated per year (11). However, a study conducted in New Jersey shows that 70% to 75% of the oil applied moves to the surrounding ecosystem from the surface of the road by dust transport and runoff. The oil or its heavy metal constituents such as lead may cause ecological harm (17). Furthermore, surface oiling requires regular maintenance because roads treated in this manner develop potholes.

Lignin sulfonates, byproducts from paper manufacture, are also used to control dust emissions. A commercially available lignin sulfonate[a] was tested on a farm access road at Arizona State University (18). The method proved quite successful, giving 5 yr of service and effective dust suppression at a cost of $\$0.47/m^2$ for 5 yr ($\$0.10/m^2$-yr).

Paving the road surface is the best method for controlling dusts, but it is impractical due to its high cost and the temporary nature of crushed limestone plants.

The simplest and least expensive means of controlling dust from crushing, screening, conveying and stockpiling is through the use of wetting agents and sprays at critical points. A crushed rock production plant uses a dust suppression system[b] and a chemical wetting agent. Approximately 0.004 m^3 of the concentrated wetting agent is diluted 1,000 times by volume with water using an automatic proportioner. The solution is sprayed at the top and bottom of cone crushers at the rate of 0.0042 m^3 of solution per metric ton of material being crushed. This system also helps in

---

[a] Orzan A., supplied by Crown-Zellerback Corporation.

[b] Chem-Jet, supplied by Johnson-March Corporation.

---

(16) Hoover, J. M. Surface Improvement and Dust Palliation of Unpaved Secondary Roads and Streets. ERI Project 856-S, Iowa State Highway Commission, Des Moines, Iowa, July 1973. 97 pp.

(17) Freestone, F. J. Runoff of Oils from Rural Roads Treated to Suppress Dust. EPA R2-72-054, U.S. Environmental Protection Agency, Cincinnati, Ohio, October 1972. 29 pp.

(18) Bub, R. E. Air Pollution Alleviation by Suppression of Road Dust. M.S.E. Thesis, Arizona State University, Tempe, Arizona, June 1968. 45 pp.

reducing dust emissions at transfer points, screening operations, storage bins, and stockpiling operations (19). Such a system has many cost-saving advantages. It requires no ducts, hoods, or other enclosures for crushers, screens, or conveyors. The equipment is in the open and allows the operators to see the entire material flow. Dust is not collected, and there are no solid waste disposal or water pollution problems.

In a crushed stone plant (with processes similar to those of a crushed limestone plant), a baghouse is used to control dust emissions from cone crushers, scalping screens, and twin sizing screens, and at the shuttle and transfer conveyors. The range of dust collected is 2,722 kg to 5,443 kg in a 10-hr day from a 182-metric ton/hr plant (20). A baghouse does not provide for dust control in stockpile areas unless these areas are totally enclosed.

The dust collected in the baghouse presents a solid waste problem. The alternative disposal methods are to put the dust into settling basins or to develop sales opportunities. Depending on the type of material and the local market conditions, uses may include manufactured sand, underslab fill, and asphalt filler (21).

---

(19) Harger, H. L. Methods Used by Transit Mix Operators to Meet Air Pollution Control District Requirements. National Sand and Gravel Association and National Ready Mixed Concrete Association, Washington, D.C., April 1971. 22 pp.

(20) Trauffer, W. E. Maine's New Dust-Free Crushed Stone Plant. Pit and Quarry, 63(2):96, 1970.

(21) Ozol, M. A., S. R. Lockete, J. Gray, R. E. Jackson, and A. Preis. Study to Determine the Feasibility of an Experiment to Transfer Technology to the Crushed Stone Industry. Contract NSF-C826, National Science Foundation, June 1974. 50 pp.

SECTION 6

GROWTH AND NATURE OF THE INDUSTRY

PRESENT TECHNOLOGY

Present technological improvements include the use of larger and more efficient crushing and screening plants. Primary crushing is often done near the pit with jaw or impact crushers. Secondary crushing is done by cone crushers or impact crushers. The crushed limestone is screened and sent to open area storage.

EMERGING TECHNOLOGY

This study did not reveal emerging technology of specific importance to air pollution control in the crushed limestone industry.

PRODUCTION TRENDS

Production of crushed limestone is tied closely to the product consuming industries. Since the construction industry consumes more than 67% of the output, the production of crushed limestone is associated chiefly with the needs of this industry (3). Production of crushed limestone was 6.1×10^8 metric tons in 1972. In 1973, 7.0×10^8 metric tons and in 1974, 6.8×10^8 metric tons of crushed limestone were either shipped to or used by producers in the United States (22).

Assuming the same annual growth rate as that for the crushed stone industry (3.5% to 5.1%), the contingency forecast of crushed limestone demand in the year 2000 is 1,200 to 2,000 $\times 10^6$ metric tons.

Transportation constitutes a major part of the delivered cost of crushed limestone. These costs may exceed the sales value of the material at the processing plants, which are therefore located near the point of use. Local zoning and environmental regulations and depletion of urban deposits may necessitate the location of future plants much farther from the point of use. This should increase the use of rail and barge systems to hold down transportation costs. Truck haulage will remain important,

---

(22) Mineral Industry Surveys. Annual Advance Summary. U.S. Department of the Interior, Washington, D.C., September 17, 1975. 12 pp.

especially for local delivery of crushed products, despite the use of rail and water transportation for long distances to central distribution points. These factors will undoubtedly result in an increase in the delivered price of crushed limestone.

REFERENCES

1. Kirk-Othmer Encyclopedia of Chemical Technology, Second Edition, Vol. 12. John Wiley & Sons, Inc., New York, New York, 1969. pp. 414-423.

2. 1972 Census of Mineral Industries, Subject Series: General Summary. MIC 72(1)-1, U.S. Department of Commerce, Washington, D.C., 1975. 174 pp.

3. Mineral Industry Surveys. U.S. Department of the Interior, Washington, D.C., 1972. 12 pp.

4. Sax, N. J. Dangerous Properties of Industrial Materials, Third Edition. Reinhold Book Corporation, New York, New York, 1968. pp. 1088-1089.

5. TLVs® Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1976. American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1976. p. 32.

6. Blackwood, T. R., P. K. Chalekode, and R. A. Wachter. Source Assessment: Crushed Stone. Contract 68-02-1874, U.S. Environmental Protection Agency, Cincinnati, Ohio, July 1977. 91 pp.

7. 1972 National Emissions Report. EPA-450/2-74-012, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 1974. 422 pp.

8. Turner, D. B. Workbook of Atmospheric Dispersion Estimates. Public Health Service Publication No. 999-AP-26, U.S. Department of Health, Education, and Welfare, Cincinnati, Ohio, May 1970. 84 pp.

9. Nonhebel, G. Recommendations on Heights for New Industrial Chimneys. Journal of the Institute of Fuel, 33:479, 1960.

10. Blackwood, T. R., and R. A. Wachter. Source Assessment: Coal Storage Piles. Contract 68-02-1874, U.S. Environmental Protection Agency, Cincinnati, Ohio, July 1977. 96 pp.

11. Jones, H. R. Fine Dust and Particulates Removal. Noyes Data Corporation, Park Ridge, New Jersey, 1972. 307 pp.

12. Grossmueck, G. Dust Control in Open Pit Mining and Quarrying. Air Engineering, 10(25):21, 1968.

13. Dust Suppression. Rock Products, 75:137, May 1972.

14. Vandegrift, A. E., L. J. Shannon, P. G. Gorman, E. W. Lawless, E. E. Sallee, and M. Reichel. Particulate Pollutant Systems Study, Volume III: Handbook of Emission Properties. Contract CPA-22-69-104, U.S. Environmental Protection Agency, Durham, North Carolina, May 1971. 607 pp.

15. Significant Operating Benefits Reported from Cement Quarry Dust Control Programs. Pit and Quarry, 63(7):116, 1971.

16. Hoover, J. M. Surface Improvement and Dust Palliation of Unpaved Secondary Roads and Streets. ERI Project 856-S, Iowa State Highway Commission, Des Moines, Iowa, July 1973. 97 pp.

17. Freestone, F. J. Runoff of Oils from Rural Roads Treated to Suppress Dust. EPA R2-72-054, U.S. Environmental Protection Agency, Cincinnati, Ohio, October 1972. 29 pp.

18. Bub, R. E. Air Pollution Alleviation by Suppression of Road Dust. M.S.E. thesis, Arizona State University, Tempe, Arizona, June 1968. 45 pp.

19. Harger, H. L. Methods Used by Transit Mix Operators to Meet Air Pollution Control District Requirements. National Sand and Gravel Association and National Ready Mixed Concrete Association, Washington, D.C., April 1971. 22 pp.

20. Trauffer, W. E. Maine's New Dust-Free Crushed Stone Plant. Pit and Quarry, 63(2):96, 1970.

21. Ozol, M. A., S. R. Lockete, J. Gray, R. E. Jackson, and A. Preis. Study to Determine the Feasibility of an Experiment to Transfer Technology to the Crushed Stone Industry. Contract NSF-C826, National Science Foundation, June 1974. 50 pp.

22. Mineral Industry Surveys. Annual Advance Summary. U.S. Department of the Interior, Washington, D.C., September 17, 1975. 12 pp.

23. Chaiken, R. F., E. B. Cook, and T. C. Ruhe. Toxic Fumes from Explosives. Ammonium Nitrate-Fuel Oil Mixtures. Bureau of Mines RI-7867 (PB 233 496), U.S. Department of the Interior, Washington, D.C., May 1974. 29 pp.

24. J. C. Ochsner, P. K. Chalekode, and T. R. Blackwood. Source Assessment: Transport of Sand and Gravel. Contract 68-02-1874, U.S. Environmental Protection Agency, Cincinnati, Ohio, October 1977. 63 pp.

25. Cheng, L. Formation of Airborne-Respirable Dust at Belt Conveyor Transfer Points. American Industrial Hygiene Association Journal, 34(12):540-546, 1973.

26. Cowherd, C. Development of Emission Factor for Fugitive Dust Sources. EPA-450/3-74-037, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 1974. 172 pp.

27. Blackwood, T. R., R. F. Boyle, T. L. Peltier, E. C. Eimutis, and D. L. Zanders. Fugitive Dust from Mining Operations. Contract 68-02-1320, Task 6, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, May 1975. p. 34.

28. Andresen, W. V. Industrial Hygiene Design in Raw Materials Handling Systems. American Industrial Hygiene Association Journal, 23(6):509-513, 1962.

29. Lilienfeld, P., and J. Dulchinos. Portable Instantaneous Mass Monitor for Coal Mine Dust. American Industrial Hygiene Association Journal, 33(3):136, 1972.

30. Eimutis, E. C., and M. G. Konicek. Derivations of Continuous Functions of the Lateral and Vertical Atmospheric Dispersion Coefficients. Atmospheric Environment, 6(11):859-863, 1972.

31. Gifford, F. A., Jr. An Outline of Theories of Diffusion in the Lower Layers of the Atmosphere. In: Meteorology and Atomic Energy 1968, Chapter 3, D. A. Slade, ed. Publication No. TID-24190, U.S. Atomic Energy Commission Technical Information Center, Oak Ridge, Tennessee, July 1968. pp. 65-116.

32. Martin, D. O., and J. A. Tikvart. A General Atmospheric Diffusion Model for Estimating the Effects on Air Quality of One or More Sources. Presented at the 61st Annual Meeting of the Air Pollution Control Association, St. Paul, Minnesota, June 23-27, 1968. 18 pp.

APPENDIX A

LITERATURE SURVEY

A study was made to predict and analyze those parameters affecting dust emissions from the seven handling operations in crushed limestone processing:

- Drilling and blasting
- Transport
- Conveying
- Unloading
- Open storage
- Loading
- Crushing/grinding/sizing

There were two major classifications of parameters: t[illegible] dependent on the material and those dependent on the ope[illegible]ion. Material-dependent parameters, generally the same for all o[illegible]-ations, are moisture content, density, and "dustiness index, which will be defined as the mass of respirable dust adhering t[illegible] 2.2 kg of material. Density delineates differences in particle size distribution between different samples of the same material. The "dustiness index" is used to determine differences in emissions from different materials undergoing the same operation. Parameters dependent on the operation are as varied as the operations themselves.

DRILLING AND BLASTING OPERATIONS

The following factors influence the dust emissions from drilling operations:

1) Number of bits
2) Sharpness of the bits
3) Speed of the bits
4) Depth of bit penetration
5) Experience of the machine operator

The literature search neither yielded quantitative data nor indicated a relationship between the emission factor (E_D) and the

aforementioned factors. A qualitative relationship might possibly resemble

$$E_D \propto \frac{(1)(3)}{(2)(4)(5)} \qquad \text{(A-1)}$$

where the numbers in parentheses represent functions of the respective variables shown above.

Of all the unit operations, dust emissions from blasting have been studied the least. The literature search yielded a potential list of factors influencing emissions: frequency of blasting, bulk moisture content of the rock, particle size distribution, type and amount of explosive, and hole size.

Studies have been conducted on the magnitude of gaseous emissions of nitrogen oxides and carbon monoxide from blasting. Stoichiometric ratios of ammonium nitrate-fuel oil (ANFO) mixtures (5.5% fuel oil) should not produce nitrogen oxide and carbon monoxide emissions. Theoretically, a higher percentage of fuel oil should not give nitrogen oxides and should yield more carbon monoxide than carbon dioxide. Conversely, a lower percentage of fuel oil should not produce carbon monoxide and should give more nitrogen oxides than nitrogen.

Experimental investigations by the Bureau of Mines (23) show that 4% fuel oil results in 1.3 m^3 (at standard conditions) of NO_x per kilogram of ANFO and 1.3 m^3 of CO per kilogram of ANFO, while 6% fuel oil results in 0.32 m^3 of NO_x per kilogram of ANFO and 1.8 m^3 of CO per kilogram of ANFO. The maximum emission factor figures have been used for the severity calculations.

TRANSPORT OPERATIONS

Transport operations are discussed in detail in another assessment document (24).

CONVEYING OPERATIONS

Dust emissions from conveying operations come from wind-blown dust during open conveying and conveyor discharge.

---

(23) Chaiken, R. F., E. B. Cook, and T. C. Ruhe. Toxic Fumes from Explosives. Ammonium Nitrate-Fuel Oil Mixtures. Bureau of Mines RI-7867 (PB 233 496), U.S. Department of the Interior, Washington, D.C., May 1974. 29 pp.

(24) J. C. Ochsner, P. K. Chalekode, and T. R. Blackwood. Source Assessment: Trnasport of Sand and Gravel. Contract 68-02-1874, U.S. Environmental Protection Agency, Cincinnati, Ohio, October 1977. 63 pp.

Emissions from conveyor discharge and parameters affecting these emissions were evaluated by Cheng (25). The material was freshly mined coal, cut during a dry operation and placed in plastic bags to maintain its natural surface moisture of about 0.8% as measured by a Soiltest Speedy Moisture Tester. Cheng found the following relationship:

$$R = 8.50 \times 10^{5} \left(\frac{A\bar{\rho}_C\sqrt{2GH}}{2MBU_B} \right)^{1.16} \qquad \text{(A-2)}$$

where R = specific formation of airborne respirable dust, g
$\bar{A}$ = cross-sectional area of the falling granules, cm^2
$\bar{\rho}_C$ = material density of the coal, g/cm^3
G = gravitational acceleration, 980 cm/s^2
H = height of fall, cm
M = belt load, g/cm^2
B = width of the conveyor belt, cm
U_B = linear speed of the conveyor belt, cm/s

Cheng concluded the following:

- About 10% of the adhering respirable dust becomes airborne by the impact of dropping.
- Reduction of the height of material fall reduces the formation of airborne respirable dust.
- For heavy belt loads (coal bed thickness much greater than mean lump size), an increase in the thickness of the coal bed reduces the specific formation of airborne respirable dust.

UNLOADING OPERATIONS

Emissions from unloading operations are produced by dropping materials from conveying machinery onto storage piles. A recent study (26) showed that the emission factor, E, for unloading operations, based on milligrams of suspended dust particles less than 30 μm in diameter per kilogram of aggregate unloaded, obeyed the following relationship:

$$E = \frac{20 \text{ mg of particulate}}{\text{kg of aggregate}} \qquad \text{(A-3)}$$

---

(25) Cheng, L. Formation of Airborne-Respirable Dust at Belt Conveyor Transfer Points. American Industrial Hygiene Association Journal, 34(12):540-546, 1973.

(26) Cowherd, C. Development of Emission Factor for Fugitive Dust Sources. EPA-450/3-74-037, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 1974. 172 pp.

This emission factor was based on high-volume sampling at a sand and gravel plant in the Cincinnati area. E was dependent on the surface moisture of the material, estimated by the Precipitation-Evaporation (P-E) Index.

For an analysis of other factors affecting emissions from unloading operations, see Appendix A, "Conveying Operations." Although the relationships derived for emissions from conveyor discharge are based on coal conveyance, only a correction factor for the relative dustiness of the material handled needs to be applied to make the equation applicable to all conveying and unloading operations.

OPEN STORAGE

Emissions due to open storage have been discussed in detail in previous documents (10, 26, 27).

LOADING OPERATIONS

Emissions from loading operations occur in the transfer of material from storage to transporting vehicles. For aggregates, this transfer is accomplished by power shovels or front-end loaders scooping the material from open storage piles and dumping it into transporting vehicles, usually trucks. Dust arises from the scooping and dropping processes.

Emissions from dropping are determined by many of the same parameters that determine dust formation from conveyor discharge, although there are definite dissimilarities in mode of discharge between conveyor belts and power shovels. Dust emissions should be determined by

1) Height of material fall
2) Quantity of material dumped
3) Density of material
4) Rate at which material is dumped
5) Moisture content of material
6) "Dustiness index" of material

An equation determining the amount of respirable dust, R, formed by power shovel discharge, based on an equation for conveyor discharge, should be of the form

---

(27) Blackwood, T. R., T. F. Boyle, T. L. Peltier, E. C. Eimutis, and D. L. Zanders. Fugitive Dust from Mining Operations. Contract 68-02-1320, Task 6, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, May 1975. p. 34.

$$R \propto \frac{(1)(3)(6)}{(2)(4)(5)} \qquad \text{(A-4)}$$

where each number in parentheses represents a function of its respective parameter as listed above.

Dust emissions from scooping operations are more difficult to define because relevant information was not available. However, the following factors are believed to play a large part in determining emissions from this source:

7) Density of material

8) Moisture content of material

9) "Dustiness index" of material

10) Degree of storage pile disturbance rendered by the scooping machinery

Although there is no basis for determining a relationship between these variables and respirable dust formation, R, a qualitative relationship might possibly resemble

$$R \propto \frac{(7)(9)(10)}{(8)} \qquad \text{(A-5)}$$

where each number in parentheses represents a function of its respective parameter as shown above.

Although not applicable to the determination of R, it has been found (25) that the emission factor, E, which can be expressed as milligrams of dust less than 30 μm in diameter emitted per kilogram of material loaded for loading crushed limestone at an asphalt plant is represented by

$$E = \frac{25 \text{ mg of dust}}{\text{kg of material loaded}} \qquad \text{(A-6)}$$

E was believed to vary with the P-E Index of the area considered.

CRUSHING/GRINDING/SIZING OPERATIONS

Emissions from crushing, grinding, and sizing operations are the result of respirable dust formation during size reduction and crusher or screen discharge.

The factors affecting discharge emissions are the same as those for conveyor and power shovel discharge (see "Conveying Operations" and "Loading Operations" sections).

Dust emissions from size reduction are judged to be influenced by

1) "Dustiness index" of material

2) Moisture content of material

3) Degree of particle-size reduction

4) Rate of material flow through size reducer

A qualitative expression for respirable dust formation, R, is believed to be

$$R \propto \frac{(1)(3)}{(2)(4)} \qquad \text{(A-7)}$$

where each number in parentheses is some function of the respective parameter listed above.

An induced air flow must be present for atmospheric dispersion of the respirable dust. For most crushers, which operate at a relatively low speed, air flow is induced only during discharge. (See "Conveying Operations" section for a quantitative evaluation of air flow induced by discharge.)

High-speed pulverizers create air flow during both size reduction and discharge. Air flow induced by high-speed size reduction may be inferred from the literature to be inversely proportional to the rate of material flow through the size reducer (28).

---

(28) Andresen, W. V. Industrial Hygiene Design in Raw Materials Handling Systems. American Industrial Hygiene Association Journal, 23(6):509-513, 1962.

APPENDIX B

SAMPLING DETAILS AND RESULTS[a]

SAMPLING SITE DESCRIPTION

The purpose of the sampling was to obtain data on the overall plant emissions and the relative contributions of the various unit operations.

Two crushed limestone plants were chosen whose operations were representative of the crushed limestone industry. In addition, these plants were located in areas with favorable meteorological conditions for sampling.

Plant A

Mining--
At the blasting site, holes are drilled in the rock in a circular pattern and then charged with ANFO and dynamite. Blasting is carried out 12 times per month at this mine. The yield is 2,700 metric tons of limestone rock per shot. The rock is loaded into 20-metric ton haul trucks by a front-end loader and transported on an unpaved road to a primary crusher and a scalping screen.

Process Plant--
The scalping screen is a 1.22 m x 1.83 m vibrating screen, and it separates material less than 80 mm in size. The oversized material is fed to a Cedar Rapids 4350S double impeller impact crusher which crushes the feed to less than 80 mm size. Undersized material from the scalping screen and crushed material from the primary crusher are conveyed to screens arranged in series.

The first screen is a 1.22 m x 3.66 m, two-deck screen that separates the material into three sizes: greater than 64 mm, 44 mm to 64 mm, and less than 44 mm. The oversized material from the screen may be stockpiled or crushed again in a Universal impact crusher and reconveyed to the screen.

The undersized material from the first screen goes to a 1.22 m x 4.27 m, three-deck horizontal screen that separates the feed into three sizes: 19 mm to 44 mm, 6 mm to 19 mm, and less than 6 mm.

---

[a]Nonmetric units appear in this appendix because they were used in the original work.

The products are stored in bins or stockpiles and loaded into trucks for shipment to customers.

The plant operates for 8 hr/day and the average processing rate through the primary crusher is 190 metric tons/hr. The number of days of operation in a year depends on both the demand for the product and the functioning of the equipment--usually about 6 mo to 8 mo/yr at 5 days/wk.

Plant B

Mining--
The mining activities are similar to those at plant A.

Process Plant--
The scalping screen is a 1.22 m x 2.44 m vibrating screen which separates material less than 100 mm in size. The oversized material is fed to a 1.07 m x 1.22 m Lippman jaw crusher which crushes the feed to less than 100 mm size. The undersized material from the scalping screen and the crushed material from the primary crusher are conveyed to a 1.52 m x 3.66 m horizontal screen. This screen separates the material into less than 50-mm and greater than 50-mm particles. The oversized material (greater than 50 mm) goes through two shorthead cone crushers. The undersized (less than 50 mm) material and the material from the cone crushers are conveyed to a 1.83 m x 4.88 m, three-deck horizontal screen. This screen separates the material into three different sizes: 19 mm to 50 mm, 13 mm to 19 mm, and less than 13 mm. The products are stored in bins or stockpiles prior to shipment.

The plant operates for 8 hr/day and the average processing rate through the primary crusher is 330 metric tons/hr. The plant operates for 8 mo/yr at 5 days/wk.

Both plants A and B control emissions from unpaved roads by spraying the roads with oil. Sampling data and results are given later in Tables B-4, B-5, and B-6.

SAMPLING PROCEDURES

Samplers

General Metal Works high-volume samplers[a] were positioned around an area as shown in Figure B-1. For this arrangement, the origin was defined at the source, and all remaining points were defined in the Cartesian coordinate system. The angle of mean wind direction was θ. The downwind distance of any point y_i perpendicular to the wind direction centerline was computed in the following manner:

[a]General Metal Works, Inc., 8368 Bridgetown Road, Cleveland, Ohio 45002.

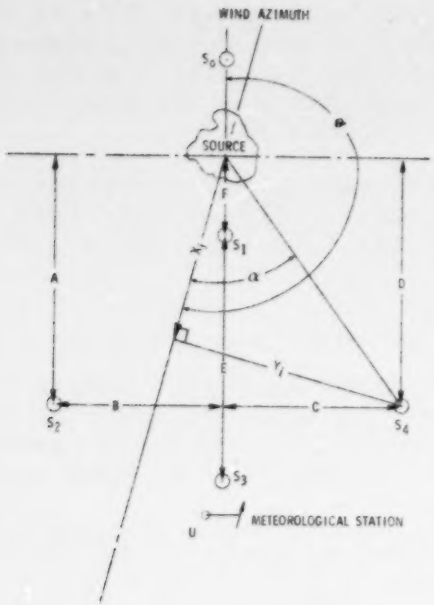

Figure B-1. Sampling arrangement.

$$m_1 = \tan \theta \tag{B-1}$$

and for point S_i with coordinates x_i, y_i,

$$m_2 = \frac{y_i}{x_i} \tag{B-2}$$

The angle α was found from

$$\alpha = \arctan \frac{m_1 - m_2}{1 + m_1 \cdot m_2} \tag{B-3}$$

The lateral distance Y_i is

$$Y_i = (\sin \alpha) \sqrt{x_i^2 + y_i^2} \tag{B-4}$$

and the downwind distance X_i is

$$X_i = (\cos \alpha) \sqrt{x_i^2 + y_i^2} \tag{B-5}$$

These values are used in appropriate dispersion models. The sampling time for high-volume samplers was about 4 hr. Five different high-volume samplers were used to monitor the area emissions at positions S_0, S_1, S_2, S_3, and S_4.

A GCA[a] respirable dust monitor was used to obtain downwind concentrations of respirable and total particulates from unit operations (29). The sampling time for the GCA instrument was about 4 min; hence, only one unit was necessary to monitor at all the positions (not simultaneously).

The high-volume samplers collect particles less than 100 μm in size, while the GCA unit collects less than 10-μm particles with a cyclone separator and less than 50-μm particles without a cyclone separator.

Models

Open source sampling uses diffusion models in reverse. It is used to predict concentrations surrounding a point source of known strength. Several concentration readings are taken to calculate the source strength of an open source.

Models applicable to the sampling arrangement and source characteristics are chosen and utilized for each emissive source. Three models are used in this study. The first represents emissions from drilling, front-end loading, primary and secondary crushing, and secondary screening. This is the point source model (8) where

$$\chi\ (x, y, z; H) = \frac{Q}{2\pi\sigma_y\sigma_z u} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \cdot \cdot \cdot \qquad \text{(B-6)}$$

$$\cdot \cdot \cdot \left\{ \exp\left[-\frac{1}{2}\left(\frac{z - H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z + H}{\sigma_z}\right)^2\right] \right\}$$

The notation used to depict the concentration is χ (x, y, z; H). H, the height of the plume centerline from the ground level when it becomes essentially level, is the sum of the physical stack height, h, and the plume rise, ΔH. The following assumptions are made: the plume spread has a Gaussian distribution in both the horizontal and vertical planes, with standard deviations of plume concentration distribution in the horizontal and vertical of σ_y and σ_z, respectively; the mean wind speed affecting the plume is u; the uniform emission rate of pollutants is Q; and total reflection of the plume takes place at the earth's surface; i.e., there is no deposition or reaction at the surface. Any consistent set of units may be used. The most common is χ in grams per cubic meter; Q in grams per second; u in meters per second; and

---

[a]GCA Corporation, GCA Technology Division, Bedford, Massachusetts.

---

(29) Lilienfeld, P., and J. Dulchinos. Portable Instantaneous Mass Monitor for Coal Mine Dust. American Industrial Hygiene Association Journal, 33(3):136, 1972.

σ_y, σ_z, H, x, y, and z in meters. The concentration χ is a mean over the same time interval as the time interval for which the σ's and u are representative. The values of both σ_y and σ_z are evaluated in terms of the downwind distance, x, and stability class. Stability classes are determined conveniently by graphical methods, Figure B-2 (27). Continuous functions are then used to calculate values for σ_y and σ_z, Tables B-1 and B-2, given the downwind distance, x (30). In open source sampling, the sampler is maintained in the center of the plume at a constant distance; the plume has no effective height (H equals 0); and the concentrations are calculated at ground level. Equation B-6 thus reduces to (8)

$$\chi\ (x,\ 0,\ 0;\ 0) = \frac{Q}{\pi \sigma_y \sigma_z u} \qquad \text{(B-7)}$$

The second model is used to describe emissions from belt conveying and transporting on unpaved roads. In this equation, instantaneous puff concentrations are described by Equation B-8 (31):

$$\psi = \left(\frac{2}{\pi}\right)^{1/2} \frac{Q_D}{\sigma_{zI} u} \qquad \text{(B-8)}$$

where ψ = dose, g-s/m^3
Q_D = line source emissions per length of line, g/m
σ_{zI} = instantaneous vertical dispersion parameter, m
u = mean wind speed, m/s

For neutral stability,

$$\sigma_{zI} = 0.15\ x_c^{0.7} \qquad \text{(B-9)}$$

where x_c = crosswind distance from the line source, m

Equation B-8 is a line source diffusion model and is used to find the mass emissions per length of road or per length of conveyor belt. The value of the dose, ψ, is determined by multiplying the concentration by the actual sampling time.

The third model is used in computing total dose from a finite release in blasting. This is calculated from Equation B-10 (8):

---

(30) Eimutis, E. C., and M. G. Konicek. Derivations of Continuous Functions of the Lateral and Vertical Atmospheric Dispersion Coefficients. Atmospheric Environment, 6(11):859-863, 1972.

(31) Gifford, F. A., Jr. An Outline of Theories of Diffusion in the Lower Layers of the Atmosphere. In: Meteorology and Atomic Energy 1968, Chapter 3, D. A. Slade, ed. Publication No. TID-24190, U.S. Atomic Energy Commission Technical Information Center, Oak Ridge, Tennessee, July 1968. pp. 65-116.

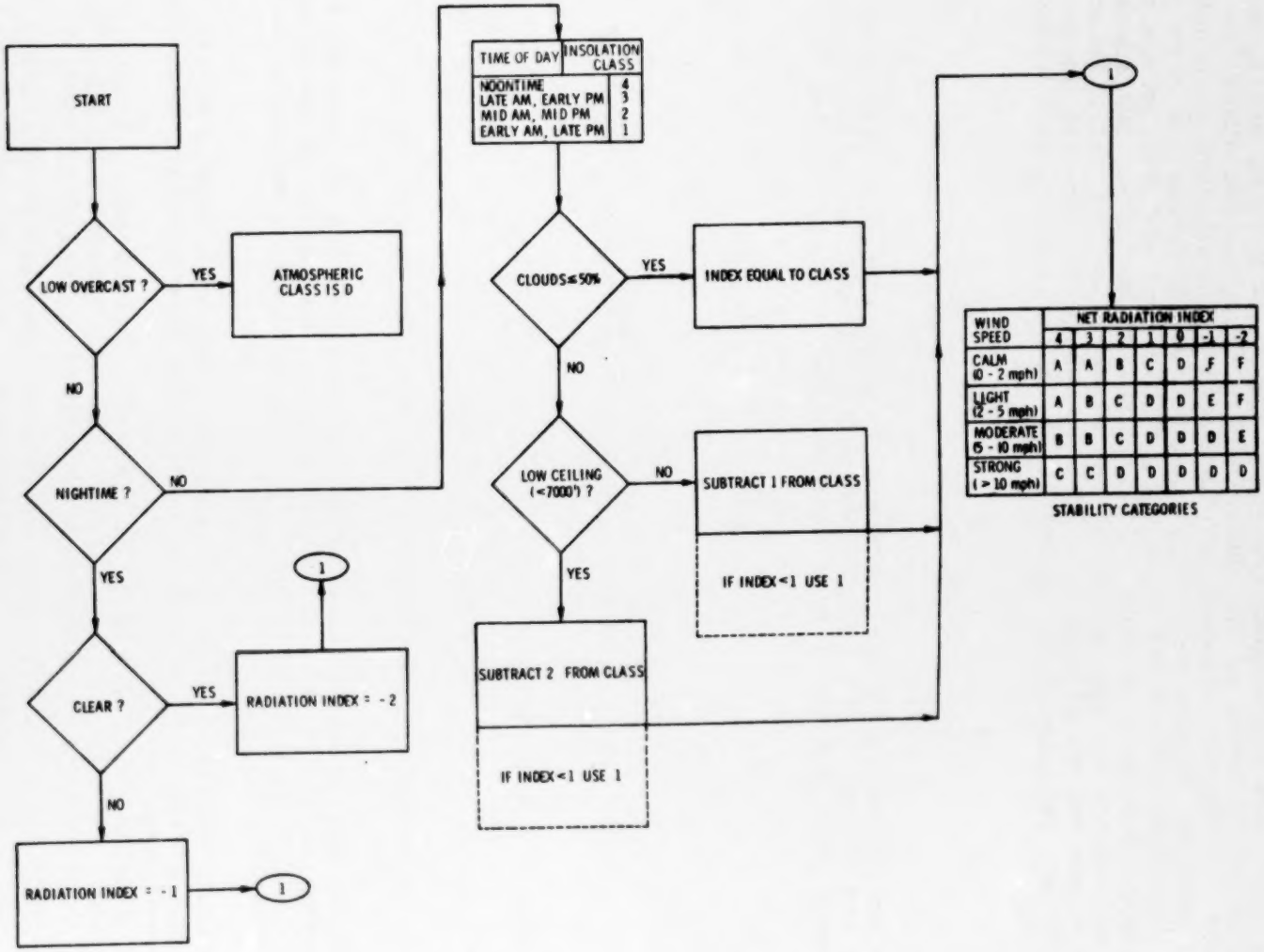

Figure B-2. Flow chart of atmospheric stability class determination.

TABLE B-2. VALUES OF a FOR THE COMPUTATION OF σ_y[a] (30)

Stability class	a
A	0.3658
B	0.2751
C	0.2089
D	0.1471
E	0.1046
F	0.0722

[a]For the equation

$$\sigma_y = ax^b$$

where x = downwind distance
b = 0.9031

TABLE B-3. VALUES OF THE CONSTANTS USED TO ESTIMATE VERTICAL DISPERSION[a] (32)

Usable range, m	Stability class	Coefficient		
		c_1	d_1	f_1
>1,000	A	0.00024	2.094	-9.6
	B	0.055	1.098	2.0
	C	0.113	0.911	0.0
	D	1.26	0.516	-13
	E	6.73	0.305	-34
	F	18.05	0.18	-48.6
		c_2	d_2	f_2
100 to 1,000	A	0.0015	1.941	9.27
	B	0.028	1.149	3.3
	C	0.113	0.911	0.0
	D	0.222	0.725	-1.7
	E	0.211	0.678	-1.3
	F	0.086	0.74	-0.35
		c_3	d_3	f_3
<100	A	0.192	0.936	0
	B	0.156	0.922	0
	C	0.116	0.905	0
	D	0.079	0.881	0
	E	0.063	0.871	0
	F	0.053	0.814	0

[a]For the equation

$$\sigma_z = cx^d + f$$

(32) Martin, D. O., and J. A. Tikvart. A General Atmospheric Diffusion Model for Estimating the Effects on Air Quality of One or More Sources. Presented at the 61st Annual Meeting of the Air Pollution Control Association, St. Paul, Minnesota, June 23-27, 1968. 18 pp.

$$D_T = \frac{Q_T}{\pi \sigma_y \sigma_z u} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \qquad \text{(B-10)}$$

The parameters of Equation B-10 use the same units as Equation B-6, except Q_T is the total release in grams from the source and D_T is the total dose, grams per second per cubic meter. Again, the dose is the product of the concentration and sampling time. Equation B-10 is therefore termed a dose model.

Data Collection

Each variable for these models was determined in the field at meteorological stations. A stationary meteorology station was used for high-volume sampling. Wind speeds were averaged every minute with a mean recorded for each 15-min interval. The mean wind speed was calculated from the average of the 15-min recordings over the entire run. The samplers were therefore maintained within the plume during sampling. The wind direction variation was less than 0.785 rad from the centerline during the samplings.

The concentration at sampler S_0 was subtracted from the concentrations at S_1, S_2, S_3, and S_4 to yield those due to the source emissions. Mass emission rate was then calculated as an average of the calculations done for N sampler readings using the appropriate dispersion equation.

The respirable dust monitor was mounted on the portable meteorological station shown in Figure B-3.

For each monitor concentration reading, displayed by direct digital readout, the mean wind speed was determined by averaging 15-s readings (a stopwatch was used) of the wind meter. This meter is connected to the anemometer which sits atop a 3.05-m pole. Distance x was approximated by pacing over the rough terrain.

These data were recorded for each sampling run on the form shown in Figure B-4 while in the field. The time of day and atmospheric stability (determined following Figure B-2) were recorded periodically on the bottom of the form.

The terms used on the field data form are explained in Table B-3.

Any factors that might have affected concentration or emission rate were mentioned in the column labeled "Comments." When this form was completed, data were programmed into a computer and emission rate, Q, was calculated in accordance with the model specified in the column labeled "M."

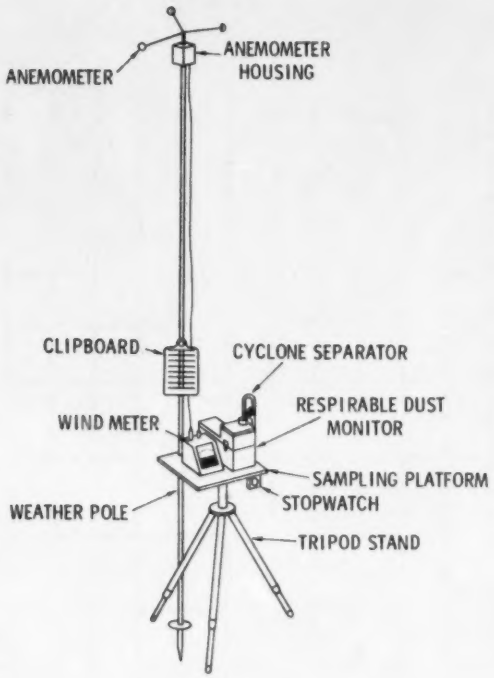

Figure B-3. Sampling apparatus.

TABLE B-3. EXPLANATION OF FIELD DATA FORM TERMS

Term	Meaning
Read., mg/m^3	Concentration reading.
Conc., $\mu g/m^3$	Converted concentration for sampling times greater than 4 min (lower right-hand corner).
R/T	R = respirable reading; T = total mass reading.
BGD, $\mu g/m^3$	Background concentration.
Δ, $\mu g/m^3$	Difference between converted concentration and background.
Q, g or g/s	Calculated emission rate.
S'	Stability for time of day unit operation was sampled.
M	Model used referenced as 1, 2, or 3 (point, line, or dose, respectively).

MODEL: POINT = 1
LINE = 2
DOSE = 3

SOURCE TYPE _____

DATE _____

BY _____

UNIT OPERATION	WIND SPEED, MPH	DISTANCE, FT. X	Y	Z	TIME, MIN.	READ., mg/m^3	CONC. $\mu g/m^3$	R/T	BGD, $\mu g/m^3$	Δ, $\mu g/m^3$	Q, g	S'	M	COMMENTS

TIME OF DAY ____ ____ ____ ____ ____

ATM. STABILITY ____ ____ ____ ____ ____

TOTAL SAMPLING TIME	MULTIPLY READING BY
4 MINUTES	1
8 MINUTES	0.46
16 MINUTES	0.23
20 MINUTES	0.184
30 MINUTES	0.122
37 MINUTES	0.1

Figure B-4. Field data form.

EMISSION LEVELS

The parameters in Equation B-6 were measured in the field in order to obtain the emission rates (Q) per unit operation. These data were recorded on the form shown in Figure B-4 and printed out via computer in Tables B-4 and B-5 where the value of Q from the appropriate dispersion model is automatically computed. Using the site data presented in Section 1 of this appendix, emission factors were computed as described below.

Blasting

From Table B-4, 36.29 g of respirable dust were emitted per shot from which 2,720 metric tons of limestone were collected and processed. Thus, the emission factor is

$$\frac{36.29 \text{ g}}{2{,}720 \text{ metric tons}} = 0.013 \text{ g/metric ton}$$

Drilling

From Table B-4, the average respirable emission rate was 2.06×10^{-4} g/s per drill. Forty hours of drilling were required for the shot of 2,720 metric tons. Thus, the emission factor is

$$\frac{2.06 \times 10^{-4} \ (3{,}600)(40)}{2{,}720} = 0.011 \text{ g/metric ton}$$

Front-End Loading at Quarry

From Table B-4, an average of 1.23×10^{-4} g/s of total particulates was emitted for the 4 min of sampling. Thus, 0.030 g was emitted in the filling of the 20-metric ton truck. Thus, the emission factor is 1.5×10^{-3} g/metric ton.

Primary Crushing

From Table B-4, 2.966×10^{-2} g/s of total particulate and 8.776×10^{-3} g/s of respirable particles are emitted while processing 190 metric tons. Thus, the emission factors are 562 and 166 mg/metric ton, respectively. Primary screening is calculated in the same manner.

Secondary Crushing

From Table B-5, 1.323×10^{-2} g/s of total particulate and an average of 7.02×10^{-3} g/s of respirable particulate are emitted while processing 330 metric tons. Thus, the emission factors are 140 and 77 mg/metric tons, respectively. Secondary screening is calculated in the same manner.

TABLE B-4. SAMPLING DATA AND RESULTS (RESPIRABLE PARTICULATES)[a]

CRUSHED LIMESTONE - PLANT A

Unit operation	U	X	Y	Z	Time	CHI	Q	Units	S
Blasting	13.5	400.0	0.0	0.0	9.0	57.0	3.629×10^{1}	g	D
Drilling	7.0	10.0	0.0	0.0	4.0	130.0	1.085×10^{-4}	g/s	D
Drilling	5.0	10.0	0.0	0.0	4.0	510.0	3.039×10^{-4}	g/s	D
Front-end loading[b]	3.0	20.0	0.0	0.0	4.0	100.0	1.231×10^{-4}	g/s	D
Primary crushing	3.0	50.0	10.0	0.0	4.0	290.0	8.776×10^{-3}	g/s	D
Primary crushing[b]	3.0	50.0	10.0	0.0	4.0	980.0	2.966×10^{-2}	g/s	D
Primary screening	3.0	20.0	0.0	0.0	4.0	20.0	2.463×10^{-5}	g/s	D

TABLE B-5. SAMPLING DATA AND RESULTS[a]

CRUSHED LIMESTONE - PLANT B

Unit operation	U	X	Y	Z	Time	CHI	Q	Units	S
Secondary crushing	3.0	60.0	10.0	0.0	4.0	120.0	3.239×10^{-3}	g/s	D
Secondary crushing	3.0	60.0	10.0	0.0	4.0	400.0	1.080×10^{-2}	g/s	D
Secondary crushing[b]	3.0	60.0	10.0	0.0	4.0	490.0	1.323×10^{-2}	g/s	D
Belt conveyors	3.0	50.0	0.0	0.0	4.0	100.0	1.463×10^{-4}	g/m-s	D
Secondary screening	2.0	30.0	0.0	0.0	4.0	40.0	6.769×10^{-5}	g/s	D
Secondary screening	2.0	30.0	0.0	0.0	4.0	10.0	1.692×10^{-5}	g/s	D
Unpaved road	2.0	70.0	0.0	0.0	4.0	80.0	1.050×10^{-4}	g/m-s	D
Unpaved road	2.0	30.0	0.0	0.0	8.0	55.2	3.433×10^{-5}	g/m-s	D
Unpaved road	2.0	30.0	0.0	0.0	4.0	30.0	1.866×10^{-5}	g/m-s	D

[a] U = wind speed, mph;
X = distance downwind, ft;
Y = distance from plume center, ft;
Z = elevation of source discharge, ft;
Time = sample time, min;
CHI = measured concentration less background, $\mu g/m^3$;
S = stability class.

[b] Total particulate measurement.

Belt Conveyors

From Table B-5, 1.463×10^{-4} g/s of respirable particles is emitted per meter of belt. Since the total length of belt was 60 m in this plant, the emission factor is

$$\frac{1.46 \times 10^{-4} \text{ g/m-s } (3{,}600 \text{ s/hr})(60 \text{ m})}{330 \text{ metric tons/hr}} = 0.096 \text{ g/metric ton}$$

Vehicular Traffic on Unpaved Roads

From Table B-5, the three emission factors in grams per meter-second are converted to grams per vehicle-meter (v-m) as follows:

$$\frac{1.05 \times 10^{-4} \text{ g/m-s } (240 \text{ s})}{(3 \text{ vehicles})} = 8.40 \text{ mg/v-m}$$

$$\frac{3.433 \times 10^{-5} \text{ g/m-s } (480 \text{ s})}{(3 \text{ vehicles})} = 5.49 \text{ mg/v-m}$$

$$\frac{1.866 \times 10^{-5} \text{ g/m-s } (240 \text{ s})}{(1 \text{ vehicle})} = 4.48 \text{ mg/v-m}$$

for an average of 6.13 mg/v-m. Since each truck (vehicle) contains 20 metric tons and travels an average of 750 m[a], the emission factor becomes

$$6.13 \text{ mg/v-m} \left(\frac{\text{vehicle}}{20 \text{ metric tons}}\right) (750 \text{ m}) = 230 \text{ mg/metric ton}$$

Respirable emissions from unpaved roads are about 18% of total particulate emissions when roads are wet (6). The roads were oiled at these limestone plants; thus only about 10% of the emissions are estimated to be respirable.

The emission factors are listed in Table B-6 along with their fractions of respirable particulates.

COMPOSITION

The emissions from both of the plants were analyzed for free silica. (For a description of the analysis methods and procedures, see Reference 6.) Table B-7 presents the free silica analysis from crushed limestone operations. The sample weight was not enough to perform trace element analysis. The trace element data provided in Table B-8 are those from previous studies.

[a]The average distance between quarry and process plant is about 750 meters for crushed stone operations (6).

TABLE B-6. PARTICULATE EMISSIONS FROM CRUSHED LIMESTONE PLANT

Operation	Emission factor		Fraction of respirable particulates, %
	Respirable particulates, g/metric ton	Total particulates, g/metric ton	
Drilling	0.011	0.11	10[a]
Blasting	0.013	0.075	17[a]
Loading at the quarry	0	0.0015	0
Vehicular traffic[b]	0.23	2.3	10
Primary crushing	0.17	0.56	30[c]
Primary screening	0.0005	0.0016	30[c]
Secondary crushing	0.077	0.14	53[d]
Secondary screening	0.0005	0.0009	53[d]
Conveying	0.096	0.32	30[c]
Wind erosion of stockpiles	-[e]	-[e]	
Unloading at stockpiles	-[e]	-[e]	
TOTAL	0.6	3.5	17

[a] Estimated from drilling and blasting operations at crushed stone plants (6).

[b] On paved road between quarry and plant.

[c] Assumed same as primary crushing. Conveying was from the primary crusher.

[d] Assumed same as secondary crushing.

[e] Negligible.

TABLE B-7. FREE SILICA ANALYSIS OF EMISSIONS FROM CRUSHED LIMESTONE PLANT

Sample	Free silica, %
1	1.2
2	<1[a]

[a] Estimate of free silica content.

TABLE B-8. TRACE ELEMENT ANALYSES OF LIMESTONE IN WEIGHT PERCENT (1)

Element	Indiana high-calcium stone	Leigh Valley, PA cement rock	Pennsylvania cement rock	Illinois Niagaran dolomitic stone
Aluminum	0.42	0.33	0.009	0.012
Arsenic	[a]	0.0011		
Barium	0.001	[a]	(<0.20)[a]	
Boron	0.00015	0.00008	(<0.005)[a]	(<0.005)[a]
Bromine	[a]			
Calcium			39	35
Carbon	0.49			
Cesium	[a]	[a]		
Chlorine	0.0038	0.00043		
Chromium	0.0076	0.0019	0.001	0.00084
Cobalt			(<0.002)[a]	(<0.001)[a]
Copper	[a]	[a]	0	0.00011
Fluorine	0.0012	0.00043		
Gallium			(<0.006)[a]	(<0.002)[a]
Iron	0.25	0.09	0.07	0.10
Lead	[a]		(<0.01)[a]	(<0.01)[a]
Lithium	0.00018	0.000031		
Magnesium	>1	0.4	0.3	2.9
Manganese	0.0140	0.015	0.025	0.011
Molybdenum				0
Nickel			(<0.002)[a]	(<0.001)[a]
Nitrogen	0.00045	0.00022		
Phosphorus	0.0085	0.005	(<0.5)[a]	
Potassium	0.058	0.033		(<0.20)[a]
Rubidium	0.00017	0.00007		
Silicon			0.24	0.65
Sodium	0.036	0.17	(<0.06)[b]	0.036
Strontium	0.15	0.22	0.039	0.078
Sulfur	0.022	0.003		
Tin			(<0.008)[a]	
Titanium	0.044	0.016	(<0.004)[a]	(<0.003)[a]
Vanadium	0.0015	0.00053		
Yttrium	[a]			
Zinc	0.0059	0.0006	(<0.06)[a]	

Note.—Blanks indicate no reported data.

[a]Not detected; numbers in parentheses indicate upper limit of element present.

[b]Trace.

APPENDIX C

SOURCE SEVERITY AND AFFECTED POPULATION

TOTAL PARTICULATES

Source Severity

Maximum source severity for particulates from ground level sources (6) is given as

$$S = \frac{4{,}020\ Q}{D^{1.814}} \qquad \text{(C-1)}$$

where S = maximum source severity
Q = emission rate, g/s
D = representative distance from the major source, m

The emission rate for total particulates from the representative plant is estimated as

Q = 450 metric tons/hr (3.50 g/metric ton) 1 hr/3,600 s
= 0.441 g/s

Substituting the values of Q and D into Equation C-1, the severity for respirable particulates is

$$S = \frac{(4{,}020)(0.441)}{(410)^{1.814}} = 0.032$$

Affected Population

The affected population is defined as the population living beyond the plant boundary where the source severity is 0.1 or greater. Since the maximum severity is less than 0.1 at the plant boundary, the affected population is zero.

FREE SILICA

Source Severity

Source severity for free silica emissions is given as (6)

$$S = \frac{316\ Q}{D^{1.814}(TLV)} \qquad (C\text{-}2)$$

where TLV is the threshold limit value for respirable dusts containing free silica in grams per cubic meter, which is given as

$$\frac{0.01}{\%\ \text{free silica} + 2} = 3.125 \times 10^{-3}\ g/m^3$$

The emission rate for respirable particulates from the representative plant is estimated as

$$Q = 450\ \text{metric tons/hr}\ (0.60\ \text{g/metric ton})\ 1\ \text{hr}/3{,}600\ \text{s}$$
$$= 0.076\ \text{g/s}$$

For free silica in respirable particulates,

$$S = \frac{(316)(0.076)}{(410)^{1.814}\ (3.125 \times 10^{-3})} = 0.14$$

Affected Population

$$X_S = \text{distance from source}$$
$$= \left[\frac{(316)(0.076)}{(S)(3.125 \times 10^{-3})}\right]^{1/1.814}$$

For $S = 0.1$, $X_{S=0.1} = 0.49$ km

Since the distance of the plant boundaries is 0.26 km from the major source, the affected area is

$$\pi(0.48^2 - 0.41^2) = 0.20\ km^2$$

For a representative population density of 58 persons/km^2, the affected population is 11 people.

NITROGEN OXIDES AND CARBON MONOXIDE

The source severity for nitrogen oxides is calculated from Equation C-3 (6):

$$S_{NO_x} = \frac{22{,}200\ Q}{D^{1.90}} \qquad (C\text{-}3)$$

The emission rate for nitrogen oxides from the representative plant is estimated as

$$Q = 450\ \text{metric tons/hr}\ (2.85\ \text{g/metric ton})\ 1\ \text{hr}/3{,}600\ \text{s}$$
$$= 0.359\ \text{g/s}$$

Severity is thus 0.089 at 410 m, and the affected population is zero.

Severity for carbon monoxide is calculated from Equation C-4 (6):

$$S_{CO} = \frac{44.8\ Q}{D^{1.81}} \qquad \text{(C-4)}$$

The carbon monoxide severity is thus 1.7×10^{-4} at 410 m, with zero affected population.

GLOSSARY

amorphous: Without stratification or other division; uncrystallized.

ANFO: Ammonium nitrate and fuel oil mixture used as an explosive.

azimuth: Horizontal direction expressed as the angular distance between the direction of a fixed point (as the observer's heading) and the direction of the object.

cone crusher: Vertical shaft crusher having a conical head.

confidence interval: Range over which the true mean of a population is expected to lie at a specific level of confidence.

dustiness index: Reference used in measuring the amount of dust settled where a material is dropped in an enclosed chamber.

emission burden: Ratio of the total annual emissions of a pollutant from a specific source to the total annual state or national emissions of that pollutant.

fibrosis: Growth of fibrous connective tissue in an organ in excess of that naturally present.

free silica: Crystalline silica defined as silicon dioxide (SiO_2) arranged in a fixed pattern (as opposed to an amorphous arrangement).

hazard factor: Measure of the toxicity of prolonged exposure to a pollutant.

impact crusher: Lightweight crusher for breaking medium-to-soft ores.

jaw crushers: Crushers that give a compression or squeeze action between two surfaces.

limestone: Rock consisting mainly of calcium carbonate.

noncriteria pollutant: Pollutant for which ambient air quality standards have not been established.

precipitation-evaporation wndex: Reference used to compare the precipitation and temperature levels of various P-E regions of the United States.

processing plant: Portion of the quarry where the operation of crushing and size classification of stone occurs.

pulverizer: Crusher used to reduce stone size into powder or dust.

quarry: Term used to refer to the mining, processing plant, and material transfer operations.

representative source: Source that has the mean emission parameters.

respirable particulates: Particles with a geometric mean diameter less than or equal to 7 μm.

rock: Stone in a mass.

severity: Hazard potential of a representative source defined as the ratio of maximum time-averaged concentration to the hazard factor.

shorthead: Refers to a cone crusher.

shuttle conveyor: Conveyor used to move crushed stone back and forth between operations.

silicosis: Diffuse fibrosis of the lungs caused by the chronic inhalation of silica dust less than 10 μm in diameter.

sizing screen: Mesh used to separate stone into various sizes.

stone: Hard, solid, nonmetallic mineral matter of which rock is composed.

thixotropic: Relating to a property of gels to become liquid when shaken or disturbed.

threshold limit value: Concentration of an airborne contaminant to which workers may be exposed repeatedly, day after day, without adverse effect.

*U.S. GOVERNMENT PRINTING OFFICE:1976 260-980/53 1-3